Effect of Polyester and Vinylester Resin Blends on the Physical and Mechanical Properties of Reinforced Composites Coconut Coir Fiber

Muhammad Restu[1]*, Rahmat Fajrul[2]

[1,2,3]Program Studi Sarjana Terapan, D Iv Teknik Mesin Produksi Dan Perawatan, Jurusan Teknik Mesin, Politeknik Negeri Bengkalis, Indonesia
Coresponden author:
Email: **restumhd02@gmail.com**

Abstract.
This study aims to determine the effect of polyester and vinylester resin blends on the physical and mechanical properties of coconut coir fiber-reinforced composites. Coconut coir fiber was selected due to its abundant availability, although its utilization remains limited. Composites were fabricated using the hand lay-up method with a matrix blend of 70% polyester resin and 30% vinylester resin, with fiber volume fractions of 0%, 5%, 10%, 15%, and 25% (PV0–PV25). Mechanical testing was conducted using a Universal Testing Machine referring to the ASTM D638 standard, while fracture morphology was characterized using Scanning Electron Microscopy (SEM). The results showed that the PV0 specimen exhibited the highest mechanical properties, with a Tensile Strength of 32.30 MPa, Yield Strength of 26.95 MPa, Elongation at Yield of 2.28%, and Tensile Stress at Break of 11.95 MPa. The addition of coconut coir fiber instead reduced the composite's mechanical properties, supported by SEM results revealing fiber pull-out and void formation in the fiber-reinforced specimens. These findings indicate that the quality of fiber-matrix interfacial bonding and the minimization of microdefects play a more critical role in determining mechanical performance than the fiber volume fraction itself.

Keywords: *composite, coconut coir fiber, polyester resin, vinylester resin, mechanical properties and SEM.*

I. INTRODUCTION

The coconut tree (Cocos nucifera) is a plantation commodity commonly found in tropical regions, particularly in Indonesia. Almost every part of the coconut plant can be utilized, from the fruit and leaves to the trunk and even the coconut fiber. However, the use of coconut fiber is still relatively limited, with most of it being used for low-value products, potentially leading to waste if not managed properly. The abundant availability of coconut fiber makes it a potential source of natural fiber for development as an engineering material.

Natural fibers are of particular interest in the development of environmentally friendly composites because they are renewable, lightweight, readily available, and relatively low cost. One potential natural fiber is coir, the outermost layer of the coconut fruit. Coir fiber has a high lignin content, providing good resistance to moisture, decay, and aggressive environments. Furthermore, this fiber has good energy absorption and promising mechanical properties for lightweight structural applications.

The resin matrix plays a crucial role in determining the physical and mechanical properties of composites. Polyester resin is widely used due to its relatively low cost and ease of processing, but it has limitations in terms of mechanical and chemical resistance. Vinylester resin, on the other hand, offers superior mechanical properties and chemical resistance, but at a higher cost. Therefore, blending polyester and vinylester resins is expected to produce composite materials with optimal properties and lower costs.

Based on the description, it is necessary to conduct research to determine the effect of a mixture of polyester and vinylester resins on the physical and mechanical properties of coconut fiber composites, so that the most effective and applicable resin composition for the development of natural fiber-based composite materials can be determined.

II. RESEARCH METHODOLOGY

General Design or Case Study

This experimental study aimed to determine the effect of a mixture of polyester and vinylester resins on the physical and mechanical properties of coconut fiber-reinforced composites. The research design was carried out systematically, starting from material preparation and specimen preparation to testing and analysis of the results.

The case study focused on the use of coconut fiber as a composite reinforcement, considering its abundant availability and potential as an environmentally friendly alternative. The matrix used was a mixture of polyester and vinylester resins with varying compositions depending on the research variables.

The composite is manufactured using the hand lay-up method. The coconut fiber is first cleaned and dried, then mixed into a resin matrix. The molded specimen then undergoes a curing process until it hardens and stabilizes.

After curing, the specimens were cut according to the applicable testing standards. The tests included tensile testing, physical properties (density and water absorption), and microstructural observations using SEM. The test data was analyzed to determine the effect of the resin mixture on the composite's characteristics and to determine the optimal resin composition.

Research Design Method

The research design method explains the sequential stages of the research, starting from planning and implementation, to data collection and analysis techniques. This method is designed to ensure the research process runs smoothly, is directed, and aligns with the desired objectives, namely to determine the effect of coconut fiber use on the mechanical and physical properties of composites with a mixed polyester and vinylester matrix.

This research employed an experimental method, directly creating composite specimens using varying coconut fiber compositions. The resulting specimens were then tested in the laboratory to obtain quantitative data, which was then analyzed to form the basis for drawing conclusions.

Experimental Design and Specimen Planning

The experimental design in this study aimed to determine variations in material composition and the number of test specimens for each variation. Each composite composition combination was produced in multiple test specimens to ensure consistent and reliable data and minimize the possibility of measurement errors.

The composition variations applied in this study include:

1. Percentage of coconut fiber, namely 0%, 5%, 10%, and 15%, 25% as composite reinforcing material.
2. Resin matrix composition, which consists of 100% polyester resin and a mixture of polyester–vinylester resin with a ratio of 70% : 30%.

This variation design allows researchers to directly analyze the effect of changes in material composition on the mechanical properties and physical characteristics of the resulting composite.

Table1Composite Specimen Variations

No	Coconut fiber (%) To (g)	Polyester & Vinylester (70:30%)	Specimen code	Results
1	0	100	PV0	
2	5 (2g)	95	PV5	

3	10 (5g)	90	PV10	
4	15 (7g)	85	PV15	
5	25 (12g)	75	PV25	

III. DATA ANALYSIS AND RESULTS

Description of Specimen Making Results

Specimen Making Process

The manufacture of coconut fiber composite specimens reinforced with a mixture of polyester and vinylester resins was carried out using the hand lay-up method according to the procedures described in Chapter III. The process begins with the preparation of a mold that has been coated with a release agent to facilitate the removal of the specimen after the curing process. The coconut fiber that has been ground with a blender is then weighed according to the specified volume fraction variations in gram units, namely 0g, 2g, 5g, 7g, and 12g.

The resin matrix was made by mixing polyester resin and vinylester resin in a 70:30 ratio, then adding MEKP catalyst and stirring until homogeneous using a magnetic stirrer. The matrix mixture was then poured into the mold gradually while arranging the coconut fibers, so that the fibers were evenly distributed throughout each specimen.

During the manufacturing process, observations were made for example on the appearance of air bubbles, surface irregularities, or uneven fiber distribution at certain volume fraction variations. The curing process was carried out at room temperature for 3 hours until the composite material hardened completely before being released from the mold.

After the hardening process is complete, the specimen is released from the mold and continued with the finishing process in the form of cutting and smoothing the edges according to the standard size of the ASTM D638 tensile test specimen (Figure 2.11). From the entire process, a total of [number of specimens, for example: 25 specimens from 5 variations of composite specimens are obtained which are ready to be used for testing physical and mechanical properties.

Physical Condition of Specimens in Each Variation

Visually, the resulting composite specimens showed differences in surface characteristics for each variation in the volume fraction of coconut fiber. In specimens with a volume fraction of 0% (without added fiber), the composite surface appeared transparent, typical of resin, and the fibers were clearly visible. As the fiber volume fraction increased (5%, 10%, 15%, and 25%), the specimen surface showed a change in color to a darker/brownish color, a rougher surface texture, and a more clearly visible fiber distribution.

In the variation with the highest fiber volume fraction (25%), indications of porosity, air bubbles, or areas with uneven fiber distribution were observed, possibly caused by the resin's limited ability to wet the entire fiber surface at high fiber content. This condition is an initial note that will be further linked to the results of physical and mechanical property tests in the next sub-chapter.

In general, all the specimens produced met the dimensional and surface quality standards required for testing, so they can be used for the density, water absorption, tensile testing, and SEM observation stages.

Mechanical Properties Test Results (Tensile Test)

Mechanical property testing was conducted to determine the ability of coconut fiber composites with a mixed matrix of polyester and vinylester resins to withstand tensile loads.This aims to obtain the mechanical characteristics of the material, such as maximum tensile strength (Tensile Strength), yield stress (Yield Strength), strain at yield (Elongation at Yield), and stress at break

(Tensile Stress at Break). The test data is used to analyze the effect of variations in fiber composition on the mechanical properties of the resulting composite.

Tensile testing was conducted using a Universal Testing Machine (UTM) in accordance with the ASTM D638 standard, thus establishing a relationship between the applied tensile load and the specimen's deformation response to fracture. All specimens were tested under the same conditions and procedures to allow objective comparisons between composite variations. Furthermore, the test data were presented in tables and graphs, and then analyzed to determine the effect of fiber composition variations on the mechanical properties of the composites.

Tensile Test Result Data

Tensile testing was conducted on coconut fiber composite specimens with a mixed matrix of polyester and vinylester resins using a Universal Testing Machine (UTM) according to ASTM D638 standards. Each composition variation was tested as many times asThe test was repeated five times to obtain more representative data. Observed parameters included Tensile Strength (TS), Yield Strength (Sy), Tensile Stress at Break (TSb), and Elongation at Yield (Ey). The test results were then processed into average values and standard deviations to determine the trend and level of data distribution in each specimen variation.

Table1Composite Tensile Test Results 0%

Variation	TS (MPa)	Sy (MPa)	TSb (MPa)	Ey (%)
PV0-1	30.77	24.88	18.39	2.2
PV0-2	34.74	27.64	17.67	2.1
PV0-3	35.82	28.25	0.8	2.0
PV0-4	27.88	23.44	10.94	2.8
Average	32.30	26.05	11.95	2.28

Table 2Composite Tensile Test Results 5%

Variation	TS (Mpa)	Sy (Mr.)	TSb (Mpa)	Ey (%)
PV5-1	21.15	18.83	5.0	18.03
PV5-2	25.36	23.92	1.1	1.1
PV5-3	16.59	15.75	7.7	0.6
PV5-4	8.7	2.0	2.0	0.3
Average	17.95	14.93	3.95	0.70

Table3Composite Tensile Test Results 10%

Variation	TS (Mpa)	Sy (Mr.)	TSb (Mpa)	Ey (%)
PV10-1	18.39	14.66	4.3	0.7
PV10-2	19.71	19.71	7.6	1.0
PV10-3	16.23	13.34	1.1	1.0
PV10-4	14.78	13.70	1.6	0.6
PV10-5	15.62	14.90	7.8	0.6
Average	16.95	15.26	4.48	0.78

Table4Composite Tensile Test Results 15%

Variation	TS (Mpa)	Sy (Mr.)	TSb (Mpa)	Ey (%)
PV15-1	21.75	19.11	1.3	0.8
PV15-2	12.38	10.34	1.2	0.5
PV15-3	11.18	11.18	1.1	0.6
PV15-4	18.87	17.67	1.4	0.7
PV15-5	18.27	16.71	1.3	0.7
Average	16.49	15.00	1.26	0.66

Table5Composite Tensile Test Results 25%

Variation	TS (Mpa)	Sy (Mr.)	TSb (Mpa)	Ey (%)
PV25-1	16.95	14.06	1.8	0.6
PV25-2	19.47	17.55	6.6	0.7

PV25-3	14.42	11.78	4.8	0.7
PV25-4	18.99	18.51	0.8	0.9
PV25-5	15.75	14.54	0.6	1.0
Average	17.12	15.29	2.92	0.78

Table6Average Value and Standard Deviation of Tensile Test Results

Variation	TS (MPa)	Elementary School	Sy (MPa)	Elementary School	TSb (MPa)	Elementary School	Ey (%)	Elementary School
PV0	32.30	3.17	26.95	1.97	11.95	7.06	2.28	0.31
PV5	17.57	6.18	17.04	8.04	3.95	2.60	0.70	0.29
PV10	16.95	1.83	15.26	2.30	4.48	2.85	0.78	0.18
PV15	16.49	4.04	15.00	3.56	1.26	0.10	0.66	0.10
PV25	17.12	1.91	15.29	2.44	2.92	2.38	0.78	0.15

Based on Table 6, the test results show that each composite variation produces different mechanical property values. The PV0 variation has the highest average Tensile Strength value of 32.30 MPa, while the lowest value is obtained in the PV15 variation at 16.49 MPa. The Yield Strength, Tensile Stress at Break, and Elongation at Yield values also show different tendencies in each composite variation. These differences indicate that variations in the composition of coconut fiber in the polyester and vinylester resin mixture have an effect on the mechanical properties of the composite. A more detailed discussion of each parameter will be explained in the next subchapter.

Tensile Strength Analysis

Tensile strength is one of the main parameters used to determine the ability of a material to withstand maximum tensile loads before failure. The tensile strength value indicates the maximum stress that a material can withstand due to tensile loading. In this study, the Tensile Strength value was used to analyze the effect of variations in the composition of coconut fiber in a mixture of polyester and vinylester resin matrices on the mechanical properties of the composite. The average Tensile Strength value of each composite variation is presented in Table 7 and visualized in graphical form in Figure 1.

Table7Average Tensile Strength Value of Composites

Variation	Tensile Strength (MPa)
PV0	32.30
PV5	17.57
PV10	16.95
PV15	16.49
PV25	17.12

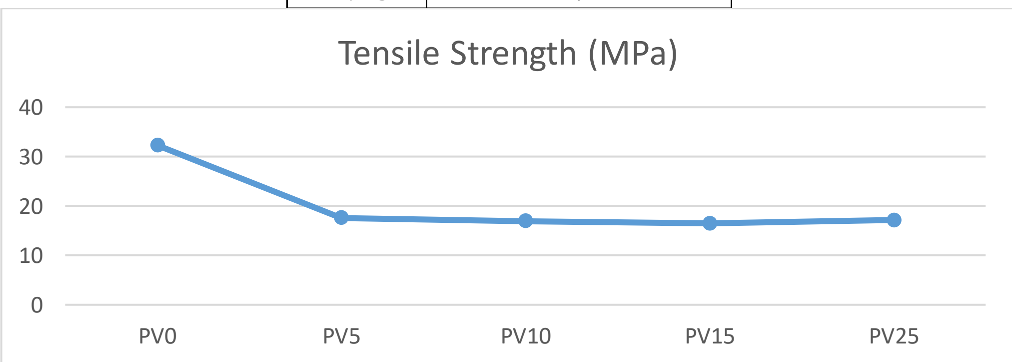


Fig. 1. Comparison Chart of Average Tensile Strength Values of Composites

Based on Table 4.7 and Figure 4.1, it can be seen that the average Tensile Strength value changes in each composite variation. The PV0 variation produces the highest Tensile Strength value of 32.30 MPa, while the lowest value is obtained in the PV15 variation of 16.49 MPa. After the addition of 5% coconut fiber, the Tensile Strength value experiences a significant decrease to 17.57 MPa or about 45.6% lower than PV0. Furthermore, the Tensile Strength value tends to be relatively stable in the PV10, PV15, and PV25 variations, although there is a slight increase in PV25 to 17.12 MPa.

The decrease in Tensile Strength indicates that the addition of coconut fiber to the composition used in this study was not able to increase the tensile strength of the composite. This condition indicates that the load transfer process from the matrix to the fiber has not occurred optimally. One factor that can cause a decrease in tensile strength is the uneven distribution of fibers in the matrix so that some of the load is still dominated by the resin. In addition, the presence of voids, poor interfacial bonding between the fiber and the matrix, and the possibility of fiber pull-out can also reduce the composite's ability to withstand tensile loads.

Although the Tensile Strength value decreased after the addition of fiber, the PV25 variation showed a slight increase compared to PV15. This indicates that increasing the number of fibers does not always cause a continuous decrease in tensile strength, but is also influenced by the quality of fiber distribution and the bond between the fiber and the matrix during the fabrication process. To determine the cause of the change in Tensile Strength value, a microstructural analysis using a Scanning Electron Microscope (SEM) is required, which will be discussed in Subchapter 4.3.

Yield Strength Analysis

Yield stress*(Yield Strength)*is the maximum stress a material can accept before undergoing plastic deformation or permanent change in shape. The Yield Strength value indicates the limit of the material's ability to return to its original shape after the load is released. The higher the Yield Strength value, the greater the material's ability to maintain its elastic properties against tensile loading. In this study, Yield Strength analysis was conducted to determine the effect of variations in the composition of coconut fiber in a mixture of polyester and vinylester resins on the composite's ability to withstand plastic deformation. The average Yield Strength value for each composite variation is presented in Table 4.8 and visualized in Figure 4.2.

Table 8Average Composite Yield Strength Value

Variation	Yield Strength (MPa)
PV0	26.95
PV5	17.04
PV10	15.26
PV15	15.00
PV25	15.29

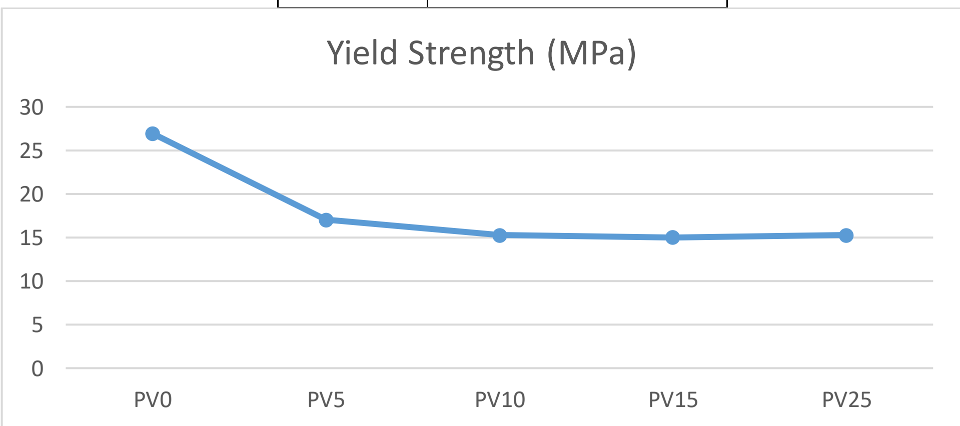


Fig .2Yield Strength Comparison Chart

Based on Table 8 and Figure 2, it can be seen that the average Yield Strength value changes in each composite variation. The PV0 variation has the highest Yield Strength value of 26.95 MPa, while the lowest value is obtained in the PV15 variation at 15.00 MPa. After the addition of 5% coconut fiber, the Yield Strength value decreases to 17.04 MPa or about 36.8% lower than PV0. The decrease continues in the PV10 and PV15 variations, then experiences a slight increase in the PV25 variation to 15.29 MPa.

The decrease in Yield Strength indicates that the addition of coconut fiber to the composition used was unable to improve the composite's ability to withstand elastic deformation before entering the plastic region. This indicates that stress transfer from the matrix to the fibers was not effective. Furthermore, uneven fiber distribution, the presence of voids, and suboptimal interfacial bonding can cause the material to undergo plastic deformation more quickly when subjected to tensile loading.

When compared with the Tensile Strength results in Section 4.2.2, the Yield Strength change pattern shows a similar trend. The PV0 variation has the highest Tensile Strength and Yield Strength values, while the variation containing fibers experiences a decrease in both parameters. This indicates that the composite's ability to maintain its elastic region is closely related to the material's ability to withstand maximum tensile loads. Thus, the higher the Yield Strength value, the higher the resulting Tensile Strength value.

To determine the cause of the change in Yield Strength, it is necessary to observe the composite's microstructure using a Scanning Electron Microscope (SEM). The SEM observations will be used to identify possible voids, fiber pull-out, or debonding that affect the material's ability to withstand plastic deformation.

Strain Analysis (Elongation at Yield)

*Elongation at Yield (Ey)*is one of the tensile test results parameters that indicates the amount of strain that occurs in the material when it reaches the yield point. This value describes the material's ability to experience an increase in length before entering the plastic deformation region. The greater the Elongation at Yield value, the material tends to have more ductile properties, while a low strain value indicates a tendency for the material to be more brittle. In this study, Elongation at Yield analysis was conducted to determine the effect of variations in the composition of coconut fiber in a mixture of polyester and vinylester resins on the deformation ability of the composite before experiencing permanent changes in shape. The average Elongation at Yield value for each variation is presented in Table 4.9 and visualized in Figure 4.3.

Table9Average Elongation at Yield Value

Variation	Ey (%)
PV0	2.28
PV5	0.70
PV10	0.78
PV15	0.66
PV25	0.78

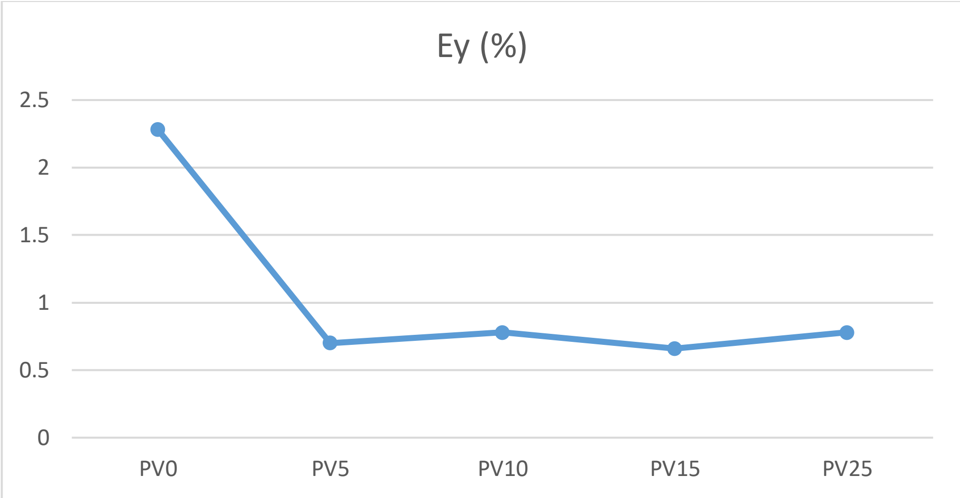


Fig. 3Elongation at Yield Comparison Chart

Based on Table 9 and Figure 3, it can be seen that the average Elongation at Yield value experienced a significant decrease after the addition of coconut fiber. The PV0 variation had the highest Elongation at Yield value of 2.28%, while the lowest value was obtained in the PV15 variation at 0.66%. After the addition of 5% fiber, the Elongation at Yield value decreased to 0.70% or approximately 69.3% lower than PV0. The strain value in the PV10 and PV25 variations was relatively the same, namely 0.78%, while PV15 experienced the lowest decrease.

The decrease in Elongation at Yield indicates that the addition of coconut fiber reduces the composite's ability to undergo elastic deformation before entering the plastic region. In other words, the composite becomes stiffer and tends to fail at lower strains than the matrix without added fiber.

This phenomenon can be influenced by several factors, such as uneven fiber distribution, the quality of the bond between the fibers and the matrix, and the presence of micro-defects in the form of voids within the composite. These conditions cause stress concentrations in certain areas, causing the material to fail more quickly when subjected to tensile loading. Furthermore, the naturally stiffer nature of coconut fiber compared to the resin matrix can also reduce the composite's ability to deform before reaching the yield point.

When compared to the Tensile Strength and Yield Strength results, the decrease in Elongation at Yield values indicates that the addition of fiber not only reduces the material's ability to withstand tensile loads but also reduces the composite's ductility. This indicates that the variation in fiber composition used in this study has not yet produced a combination that can increase strength while maintaining the material's ductility.

To determine the cause of the decrease in Elongation at Yield, morphological analysis using a Scanning Electron Microscope (SEM) is required. These observations will be used to identify fiber pull-out, voids, debonding, and matrix cracks that affect the composite's deformation capacity.

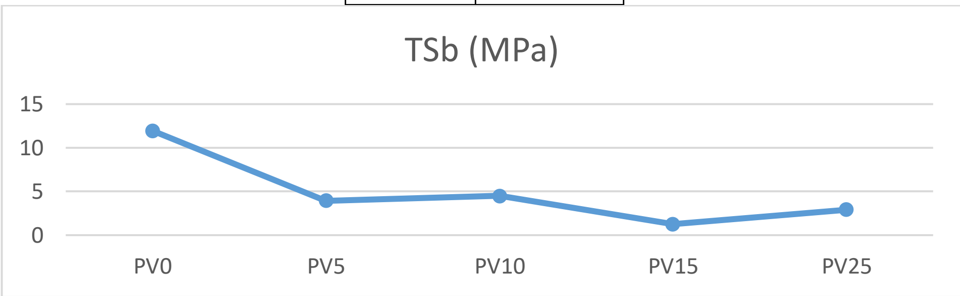
Tensile Stress at Break Analysis

*Tensile Stress at Break (TSb)*is the stress that the material can still withstand when the specimen breaks during tensile testing. This parameter indicates the composite's ability to maintain stress after reaching maximum tensile strength (Tensile Strength) until final failure (fracture) occurs. The Tensile Stress at Break value can also provide information about the material's fracture characteristics, whether the material tends to fracture brittlely or is still capable of deformation before breaking. The average Tensile Stress at Break value for each composite variation is presented in Table 10 and visualized in Figure 4.

Table10Average Tensile Stress at Break Value

Variation	TSb (MPa)
PV0	11.95

PV5	3.95
PV10	4.48
PV15	1.26
PV25	2.92



Picture4Tensile Stress at Break Comparison Chart

Based on Table 10 and Figure 4, it can be seen that the average Tensile Stress at Break value decreased in all composite variations using coconut fiber compared to the PV0 variation. The highest Tensile Stress at Break value was obtained in the PV0 variation of 11.95 MPa, while the lowest value was obtained in the PV15 variation of 1.26 MPa. After the addition of 5% fiber, the Tensile Stress at Break value decreased to 3.95 MPa or about 67.0% lower than PV0. In the PV10 variation, there was a slight increase to 4.48 MPa, but decreased again at PV15 before increasing to 2.92 MPa at PV25.

The decrease in the Tensile Stress at Break value indicates that the composite has a lower ability to maintain stress after reaching maximum tensile strength. This indicates that after passing the maximum load point, the material experiences faster crack propagation, causing the specimen to fracture quickly. This condition can be influenced by the quality of the bond between the fiber and the matrix, which is not optimal, so that stress cannot be distributed evenly throughout the composite.
Furthermore, the presence of micro-defects such as voids, debonding between fibers and the matrix, and fiber pull-out can also accelerate the material failure process. When cracks begin to form, these defects become stress concentration points, accelerating crack propagation until the specimen fractures.

When compared with the results*Tensile Strength*In Section 4.2.2, it can be seen that variations with higher Tensile Strength values also tend to have higher Tensile Stress at Break values. This indicates that composites capable of withstanding greater maximum tensile loads also tend to have better ability to maintain stress until fracture occurs. However, the Tensile Stress at Break value is not only influenced by the maximum tensile strength, but also by the failure mechanism that occurs during the loading process.

To determine the cause of changes in Tensile Stress at Break values, observations using a Scanning Electron Microscope (SEM) are required. These observations can identify fiber pull-out, debonding, voids, and matrix cracks that contribute to the composite's fracture mechanism.

Relationship Between Tensile Test Parameters

After analyzing each parameter of the tensile test results, namely*Tensile Strength (TS)*, Yield Strength (Sy), Elongation at Yield (Ey), and Tensile Stress at Break (TSb), followed by a discussion of the relationship between these parameters. This analysis aims to determine the effect of variations in coconut fiber composition on changes in the overall mechanical properties of the composite. The relationship between parameters provides an overview of the material's ability to withstand tensile loads, maintain elastic properties, undergo deformation, and ultimately fail.

Table11Summary table of TS, Sy, TSb, Ey

Variation	TS	Sy	TSb	Hey
PV0	32.30	26.95	11.95	2.28
PV5	17.57	17.04	3.95	0.70
PV10	16.95	15.26	4.48	0.78

PV15	16.49	15.00	1.26	0.66
PV25	17.12	15.29	2.92	0.78

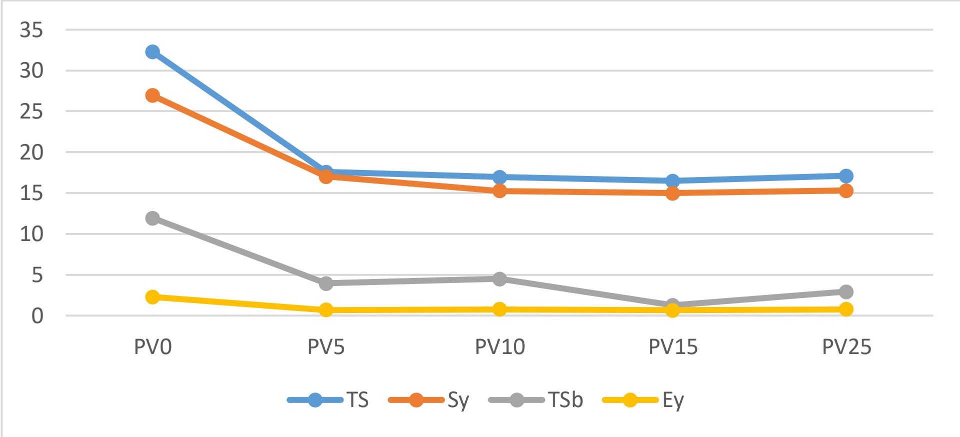


Fig. 5Comparison of TS, Sy, TSb, and Ey Values in Each Composite Variation

Based on the test results, it can be seen that changes in Tensile Strength values have the same tendency as changes in Yield Strength. The PV0 variation produces the highest TS and Sy values, while after the addition of coconut fiber, both parameters decreased. This indicates that the composite's ability to withstand maximum loads is influenced by the material's ability to maintain elastic deformation before entering the plastic region. In other words, composites with high Yield Strength tend to have higher Tensile Strength.

The Elongation at Yield value also shows a trend in line with the Tensile Strength. The PV0 variation has the highest strain value, while all variations containing fiber experience a decrease in Ey values. This condition indicates that the addition of coconut fiber to the composition of this study causes the material to become stiffer, thus reducing its deformation capacity. As a result, the composite experiences failure at a lower strain than the composite without the addition of fiber.

Tensile Stress at Break values show a trend in the same direction as Tensile Strength. Variations with high TS values also have relatively high TSb values. Conversely, variations with decreasing TS also experience a decrease in TSb values. This indicates that composites with greater maximum load-bearing capacity are generally also able to maintain stress for longer before fracturing.

In general, the addition of coconut fiber to the polyester and vinylester resin mixture caused a decrease in the values of all observed mechanical parameters. The PV0 variation showed the best mechanical performance with the highest TS, Sy, TSb, and Ey values. After the addition of 5% fiber, there was a significant decrease in all parameters. In the PV10 to PV25 variations, these values were relatively stable, although there was a slight increase in some parameters. These results indicate that under the conditions of this study, the addition of fiber was not able to optimally improve the mechanical properties of the composite.

Based on the analysis of the relationship between tensile test parameters, it can be concluded that changes in the values of Tensile Strength, Yield Strength, Elongation at Yield, and Tensile Stress at Break show a related trend. A decrease in the tensile strength value is followed by a decrease in the yield stress, strain at yield, and stress at break. This indicates that variations in the composition of coconut fiber affect the composite's ability to withstand loads, maintain elastic deformation, undergo deformation, and maintain stress before breaking. The assumption regarding the cause of these changes in mechanical properties will be discussed further based on the results of morphological observations using a Scanning Electron Microscope (SEM) in Subsection 4.3.

Microstructure Observation Results Using a Scanning Electron Microscope (SEM)

Microstructural observations using a Scanning Electron Microscope (SEM) were conducted to observe the morphology of the composite fracture surface after tensile testing. This analysis aims to determine the microstructural characteristics of the composite, including the fracture surface condition, the quality of the bond between the fiber and the matrix (interfacial bonding), and the presence of micro-defects such as voids, matrix cracks, and fiber pull-out. These characteristics affect the composite's ability to accept and distribute tensile loads so that they can be used to explain the results of the mechanical property tests discussed in Subchapter 4.2.

In this study, SEM observations were conducted on composites with a mixed matrix of 30% vinylester resin and 70% polyester resin. Observations were conducted on three specimen variations, namely PV0, PV5, and PV25, with a magnification of 1,000×. These three variations were chosen to represent the conditions of the composite without fiber addition, the composite with the initial fiber addition, and the composite with the highest fiber variation so that morphological changes due to composition variations can be observed and compared.

SEM Observation Results

SEM observations revealed differences in fracture surface morphology in specimens PV0, PV5, and PV25 after tensile testing. These differences were evident in the surface texture, fracture pattern, and the presence of micro-defects in each variation.

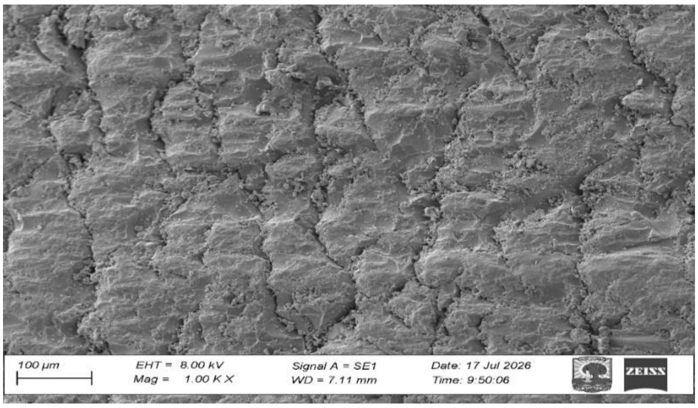


Fig. 6SEM PV0 observation results

Figure 6 shows that the fracture surface of PV0 is dominated by a resin matrix with a relatively dense and rough texture. The fracture surface appears quite homogeneous and does not show any large voids. This characteristic indicates that the matrix structure remains sufficiently continuous, suggesting that stress distribution during tensile loading is more uniform than in other variations.

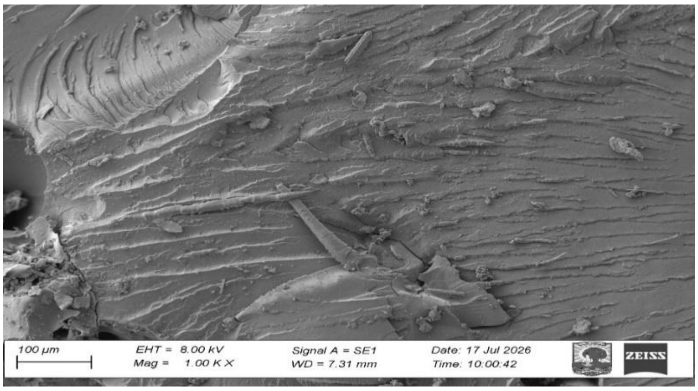


Fig .7SEM PV5 observation results

Figure 7 shows fracture lines on the composite surface, indicating the direction of crack propagation during tensile testing. Furthermore, several areas indicate fiber pull-out, the detachment of fibers from the matrix due to loading. This phenomenon indicates that the material failure process does not only occur in the matrix but also involves interactions between the fibers and the matrix.

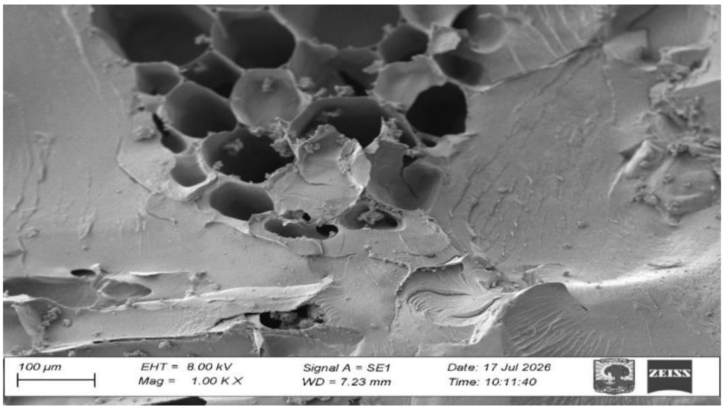


Fig.8SEM PV25 observation results

In Figure 4.8, we can see relatively large voids spread across the composite fracture surface.These cavities are accompanied by cracks around them, indicating stress concentration in those areas. Compared with PV0 and PV5, the surface of PV25 shows a more pronounced number of micro-defects, indicating a less homogeneous composite structure.

Surface Morphology Analysis

Based on the results of SEM observations, the fracture surface morphology shows changes influenced by variations in the composite composition with a matrix of 30% vinylester resin and 70% polyester resin.

In the PV0 specimen, the fracture surface is relatively more homogeneous and does not show the presence of large voids.This condition indicates that the matrix is able to form a more continuous structure so that the stress distribution during tensile testing is more even. This morphology is in line with the tensile test results which show that PV0 has the highest Tensile Strength (32.30 MPa), Yield Strength (26.95 MPa), Elongation at Yield (2.28%), and Tensile Stress at Break (11.95 MPa) values compared to other variations.

In the PV5 specimen, fracture lines and indications of fiber pull-out began to appear on the composite surface. This phenomenon indicates that when the material is subjected to tensile loading, some fibers are detached from the matrix, resulting in suboptimal stress transfer from the matrix to the fibers. This condition is suspected to be one of the causes of the decreased Tensile Strength, Yield Strength, Elongation at Yield, and Tensile Stress at Break values compared to PV0.

Meanwhile, the PV25 specimen showed a significant presence of voids on the fracture surface. Voids are micro-defects that can be the starting point for stress concentration. When a specimen is subjected to tensile loading, cracks tend to develop from void-containing areas, accelerating the material's failure process. The presence of these voids is suspected to be one of the factors causing the Tensile Strength value of PV25 to only reach 17.12 MPa, while the Tensile Stress at Break value is 2.92 MPa, which is still much lower than that of PV0.

Overall, the SEM observation results show that the more complex the micro-defects that appear on the fracture surface, such as fiber pull-out and voids, the composite's ability to withstand tensile loads tends to decrease. This indicates that the quality of the bond between the coconut fiber and the 30% vinylester–70% polyester resin matrix and the quality of the fabrication process play an important role in determining the mechanical properties of the resulting composite.

Relationship between SEM Results and Tensile Test Results

The tensile test results show that variations in composite composition have an effect on mechanical properties, as indicated by changes in Tensile Strength (TS), Yield Strength (Sy), Elongation at Yield (Ey), and Tensile Stress at Break (TSb) values.To understand the causes of these changes, a Scanning Electron Microscope (SEM) analysis of the fracture surface morphology was performed. SEM observations provide information on the microstructural conditions of the composite, such as the presence of voids, fiber pull-out, matrix cracking, and the quality of the bond between the fibers and the matrix. These microstructural characteristics are closely related to the composite's ability to absorb and distribute loads during tensile testing.

In the PV0 specimen, the SEM results show a relatively more homogeneous fracture surface compared to other variations and no large voids are visible.This condition indicates that the matrix is able to form a more continuous structure so that the stress distribution during tensile loading is more even. These results are in line with tensile testing, where PV0 has a Tensile Strength value of 32.30 MPa, Yield Strength of 26.95 MPa, Elongation at Yield of 2.28%, and Tensile Stress at Break of 11.95 MPa, which is the highest value compared to other variations. Thus, the relatively better surface morphology of PV0 supports the composite's ability to withstand tensile loads.

In the PV5 specimen, SEM results show the presence of fracture lines in the matrix and indications of fiber pull-out. This phenomenon indicates that some fibers are detached from the matrix during tensile loading, so that stress transfer from the matrix to the fibers becomes less effective. This condition is related to a decrease in mechanical properties compared to PV0, namely Tensile Strength of 17.57 MPa, Yield Strength of 17.04 MPa, Elongation at Yield of 0.70%, and Tensile Stress at Break of 3.95 MPa. These results indicate that the quality of the interfacial bond between the fiber and the matrix is one of the factors that influences the composite's ability to withstand tensile loads.

In the PV25 specimen, the SEM results show the presence of clearer voids on the fracture surface.These voids have the potential to become stress concentration points, making it easier for cracks to form and develop when the specimen receives tensile loading. The presence of these voids is thought to contribute to the decrease in mechanical properties, where Tensile Strength only reaches 17.12 MPa, Yield Strength is 15.29 MPa, Elongation at Yield is 0.78%, and Tensile Stress at Break is 2.92 MPa. Although the TS value of PV25 is slightly higher than PV15, SEM results show that micro-defects are still present in the composite structure, so the material's ability to sustain loads until fracture remains low.

Based on the results of tensile testing and SEM observations, it can be concluded that changes in the mechanical properties of the composite are influenced by the microstructural characteristics formed during the fabrication process.The PV0 specimen showed a relatively more homogeneous surface morphology and produced the best mechanical properties. In PV5, fiber pull-out indications began to appear, indicating that the bond between the fiber and the matrix was not working optimally, while in PV25, the presence of voids became more dominant, facilitating stress concentration and crack propagation. These conditions indicate that the quality of the fiber-matrix bond and the minimum number of micro-defects are important factors in improving the mechanical properties of composites based on a mixture of 30% vinylester resin and 70% polyester resin.

Overall Discussion

Based on the results of mechanical property testing through tensile testing and morphological characterization using a Scanning Electron Microscope (SEM), a comprehensive discussion can be carried out regarding the effect of variations in the composition of coconut fiber on composites with a mixed matrix of 30% vinylester resin and 70% polyester resin.This discussion aims to link the results of mechanical testing with the microstructural conditions of the composite so that a more comprehensive understanding of the behavior of the resulting material is obtained.

The Effect of Fiber Variation on Mechanical Properties

In this study, the PV0 specimen showed the highest mechanical property values compared to other variations, with Tensile Strength values of 32.30 MPa, Yield Strength of 26.95 MPa, Elongation at Yield of 2.28%, and Tensile Stress at Break of 11.95 MPa.After the addition of coconut fiber, all mechanical parameters decreased.

In general, this decrease indicates that under the conditions of this study, the addition of fiber was not able to increase the tensile strength of the composite. This indicates that the effectiveness of reinforcement is influenced not only by the number of fibers, but also by the quality of the bond between the fibers and the matrix, the distribution of the fibers, and the quality of the fabrication process.

Relationship between Tensile Test Results and SEM

The results of SEM observations show that changes in mechanical properties are related to the morphological characteristics of the fracture surface.

At PV0, the fracture surface appears more homogeneous so that the stress distribution during loading is estimated to be more even.In contrast, in PV5, indications of fiber pull-out began to appear, while in PV25, the presence of voids was more dominant.

The presence of fiber pull-out indicates that the bond between the fiber and the matrix is not yet fully capable of transferring the load effectively.Meanwhile, voids act as stress concentration points that accelerate crack initiation and propagation, leading to specimen fracture. Therefore, SEM observations support the tensile test results, which showed a decrease in TS, Sy, Ey, and TSb values in the fiber-containing variation.

Discussion Based on Theory

Theoretically, adding fibers to a composite material can improve mechanical properties if the fibers have a good interfacial bond with the matrix and are evenly distributed. Under these conditions, the load received by the matrix can be effectively transferred to the fibers, increasing the composite's strength.

Conversely, if there are micro-defects such as voids, fiber pull-out, or poor interfacial bonding, stress transfer will be suboptimal. This condition causes stress concentrations that accelerate cracking and reduce the material's ability to withstand tensile loading. The results of this study demonstrate this trend, making the quality of the fiber-matrix bond and the fabrication process critical factors in determining the mechanical properties of composites.

Implications of Research Results

The results of the study showed that the composite with a matrix of 30% vinylester resin and 70% polyester resin without added fiber (PV0) provided the best mechanical properties under the test conditions carried out.The addition of coconut fiber in variations PV5 to PV25 has not resulted in an increase in mechanical properties, which is thought to be influenced by the quality of the fiber-matrix bond and the presence of micro-defects in the composite structure.

These findings indicate that to obtain composites with better performance, optimization of the fabrication process is required, such as increasing mixing homogeneity, reducing void formation, and treating the fiber surface to strengthen the bond with the matrix.

Conclusion of Discussion of Chapter IV

Overall, the results of the study indicate that the addition of coconut fiber to a composite with a matrix mixture of 30% vinylester resin and 70% polyester resin has not provided an increase in mechanical properties based on the parameters of Tensile Strength, Yield Strength, Elongation at Yield, and Tensile Stress at Break. The results of SEM observations show the presence of fiber pull-out and voids in variations containing fiber, which are suspected to be the main cause of the decrease in the mechanical properties of the composite.Thus, the results of mechanical testing and SEM characterization support each other in explaining the behavior of the resulting composite.

IV. CONCLUSION

Based on the test results and discussion in Chapter IV regarding the effect of a mixture of polyester and vinylester resin (70:30) on the physical and mechanical properties of coconut fiber reinforced composites, the following conclusions can be drawn:

1. Observations of the physical condition of the specimens showed that increasing the volume fraction of coconut fiber caused a change in the surface color to become darker, a rougher texture,

and the appearance of indications of porosity at the highest volume fraction (25%), which indicates the effect of adding fiber on the physical characteristics of the composite.

2. Variations in the composition of coconut fiber significantly affected the mechanical properties of the composite. The PV0 specimen (without fiber) produced the highest Tensile Strength value of 32.30 MPa, Yield Strength of 26.95 MPa, Elongation at Yield of 2.28%, and Tensile Stress at Break of 11.95 MPa. The addition of coconut fiber (PV5–PV25) actually reduced all of these mechanical parameters, with the lowest values in the PV5–PV15 range.
3. The composition that produced the best mechanical properties in this study was PV0, a matrix mixture of 70% polyester resin and 30% vinylester resin without the addition of fiber. SEM observations supported this finding, where PV0 had the most homogeneous fracture morphology, while PV5 showed indications of fiber pull-out and PV25 showed more dominant voids — both of which were responsible for the decrease in mechanical properties in the fibrous variation.
4. Overall, the addition of coconut fiber in the fabrication conditions of this study has not been able to improve the mechanical properties of the composite, which indicates that the effectiveness of reinforcement is more determined by the quality of the fiber-matrix bond and the minimum micro-defects than simply increasing the number of fibers.

V. SUGGESTION

Based on the research results and conclusions, several suggestions that can be made for further research development are:

1. It is necessary to carry out complete quantitative physical properties testing (density and water absorption) so that the analysis of the effect of the resin mixture on the physical properties of the composite can be discussed in full.
2. It is necessary to treat the fiber surface (e.g. alkalization/NaOH) to improve the interfacial bond between the fiber and the matrix, so that the fiber pull-out phenomenon can be minimized.
3. The fabrication process needs to be optimized, especially in terms of mixing homogeneity and reducing void formation, so that the mechanical properties of fibrous composites can be improved.
4. Further research is recommended to test variations in other polyester-vinylester resin ratios (besides 70:30) to determine the most optimal matrix composition.
5. Additional mechanical testing such as flexural testing and impact testing need to be carried out to obtain a more comprehensive characterization of the mechanical properties of the composite.

REFERENCE

[1]. Akbar, AI (2022). The Effect of Polymer Type on the Strength of Natural Palm Fiber Composite Materials as Materials for Making Salt Pond Windmill Blades.

[2]. Fery Ferdianto, S. (2020). Analysis of Epoxy Matrix Coconut Fiber Powder Reinforced Composites on Tensile Strength. 1, 2–6.

[3]. Hidayah, E., Sujito, & Purwandari, E. (2023). Study of the Effect of Coconut Fiber and Ramie Fiber on the Tensile Properties of Polypropylene Composites Elok Hidayah 1* , Sujito 2 , Endhah Purwandari 3 1. 01(03), 122–131.

[4]. Indahyani, T. (2011). Interior and Furniture Planning for Poor Communities. 15–23.

[5]. Maryanti, B., As, A., & Wahyudi, S. (2011). The Effect of Alkalization of Coconut Fiber-Polyester Composites on Tensile Strength. 2(2), 123–129.

[6]. Nicolaus Ardi Kurniawan, Setiawan, F., & Sofyan, E. (2022). Tensile Testing of Composite Specimens of Diagonal Groove Banana Fiber and Iron Sand with Polyester Resin Matrix Using Hand Lay-Up Method 1. 8(2), 281–288.

[7]. Nurfadilah, S. (2024). The Effect of Fiber Volume Fraction and Percentage of Polyester Reinforced with Palm Fiber Using the Vacuum Bag Method Siti Nurfadilah Cilegon-Banten Polyester Reinforced with

Palm Fiber Using.
[8]. Rizaldi, FA, & Drastiawati, NS (2023). Ferdian Arsa Rizaldi Novi Sukma Drastiawati Abstract. D.
[9]. Setiawan, A., & Prihantoro, T. (2021). The Effect of Mechanical Properties of Volume Fraction of Oil Palm Empty Fruit Bunch Fiber-Reinforced Composites. 10(2), 193–199.
[10]. Sumiyanto, Achyadi, H., & Hardianto, D. (2024). Development of Polymer-Based Composite Materials. 26(2).